Radiat. Phys. Chem. Vol. 31, Nos 1-3, pp. 195-202, 1988
Int. J. Radiat. Appl. Instrum. Part C
Printed in Great Britain

EFFECT OF GAMMA IRRADIATION AT VARIOUS TEMPERATURES AND PACKAGING CONDITIONS ON CHICKEN TISSUES. I. FATTY ACID PROFILES OF NEUTRAL AND POLAR LIPIDS SEPARATED FROM MUSCLE IRRADIATED AT -20°C.

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ABSTRACT

A lipid composition study on irradiated chicken muscle is reported. All muscle samples, packed either under air or vacuum, were gamma irradiated (-20°C) at 0, 1, 3, 6 and 10 kGy using ^{137}Cs (dose rate = 0.1 kGy/min). Lipids were isolated from the muscle using a dry column extraction method with concomitant isolation of separated neutral and polar fractions. Lipid isolates were converted to their methyl esters and analyzed by capillary column gas chromatography with computer assisted data storage, followed by data consolidation and statistical computer analysis. Separated fatty acid profiles for neutral and polar lipids were obtained as normalized reports (each fatty acid as percentage of total fatty acids) and as "gravimetric" reports (mg of each fatty acid/100 g tissue). In each set, side by side profiles allowed comparative and statistically valid ($p < 0.05$) conclusions to be made for the effects of different irradiation levels at -20°C on air or vacuum packed samples. Fatty acids were grouped into classes such as saturated and unsaturated, the latter subgrouped as monoenoic, dienoic and polyenoic unsaturated for ease of comparison. Separate analysis of polar fractions allowed detailed examinations of the polyunsaturated fatty acids to be made and gave profiles representative of muscle cells separate from contiguous intramuscular adipose cells. Normalized reports showed only negligible occurrence of significant changes in fatty acid profiles of neutral muscle lipid fractions regardless of irradiation doses (0 to 10 kGy) in either air and vacuum packaging. These differences were not apparent when the data were compiled as gravimetric reports. The polar lipid fractions containing the nutritionally significant $\omega 3$ and $\omega 6$ fatty acids showed only slight changes in normalized and gravimetric reports and were similarly unaffected with increasing levels of irradiation. Additionally, no new fatty acids or other artifacts due to gamma-irradiation were observed in detectable amounts by gas chromatography in any lipid fractions.

KEYWORDS

Radiation, gamma irradiation, radiolysis, chicken, poultry, muscle, fatty acid, neutral, polar, lipid, phospholipid, polyunsaturated

INTRODUCTION

The use of ionizing radiation to extend the shelf life of poultry is now an accepted practice in several countries (1). In the Netherlands, for instance, the maximum dose approved for refrigerated poultry is 3 kGy, a level which is sufficient to kill or inactivate most spoilage organisms (2). In countries such as Israel and South Africa a dose level of 7 kGy is allowed to eliminate pathogenic bacteria such as Salmonella (3). These levels should present no health problems since expert committees of several international agencies have concluded that ionizing radiation presents no toxicological hazard and induces no special nutritional or microbiological problems when properly applied in dosages up to 10 kGy (4). However, some authors have stated that these committees have not covered the possible health effects in depth and have also pointed out that no test is currently available to identify food that has been irradiated (5). To address such concerns, extensive studies have been carried out on the individual constituents of irradiated foods to determine whether this process does result in the formation of unusual radiolytic products or in changes to the proteins and fats in poultry (6). For instance the amino acid content of chicken meat has been compared for unirradiated and irradiated samples up to 6 kGy to assess whether the amino acid patterns are affected by the radiation (7). In the case of lipids, however, no comparable study has been undertaken on the individual fatty acid patterns from the neutral glycerides and phospholipids of chicken irradiated at varying temperature and packaging conditions. Instead, most investigations carried out on the fats in poultry have been limited to the determination of the volatiles formed from fatty acids during irradiation (8), fat

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quality indices (6) and the lipid oxidation products produced from ionizing radiation (6). The present study was undertaken to provide a detailed analysis of lipid fatty acid patterns from irradiated and non-irradiated chickens. Chicken muscle was irradiated (-20°C) at doses from 0-10 kGy using both air and vacuum packaging. The lipids were extracted and simultaneously separated into neutral and polar fractions (9). After derivatization to methyl esters, the fatty acids from the neutral and polar lipid fractions were examined separately in detail to provide separate profiles of the minor but nutritionally significant polar fatty acids. This investigation presents a statistical analysis of these lipid profiles with particular emphasis on the effect of ionizing radiation on the nutritionally significant polyunsaturated fatty acids.

MATERIALS AND METHODS

Twelve fresh chickens (24 hrs post-slaughter) were hand deboned. The skin and subcutaneous fat were separated from the muscle tissue and discarded. The muscle was frozen, then ground in a bowl cutter. Samples (25 g) were wrapped in Saran film and packed in Kenfield All-Vac #13 pouches. Half of the pouches were sealed under vacuum using a Swiss Vac machine (Transvac Machine Nag, Lucerne, Switzerland) and the others were left unsealed. Both vacuum and air packaging pouches were gamma irradiated in duplicate at 0, 1, 3, 6 and 10 kGy using ^{137}Cs (dose rate 100 Gy/min) at -20°C.

Extraction of lipids: Duplicate samples (5.0 g $\pm$ 0.1 mg) were each extracted sequentially by a dry column method (9). The lipids were isolated and simultaneously separated into neutral and polar fractions by a sequential elution procedure. Neutral lipids free of polar lipids were eluted first with dichloromethane, followed by elution of polar lipids with the mixture of dichloromethane/methanol (90:10, v/v). Eluates from the individual neutral and polar fractions were collected in 200 mL round bottom flasks. Solvent was removed on a rotary evaporator at room temperature, and the contents of the flasks were transferred with hexane to 100 mL volumetric flasks and brought to volume with hexane. Separate aliquots were taken for weight determination and for derivatization to fatty acid methy esters (FAME's) for subsequent gas chromatographic analysis.

Derivatization of glycerides to methyl esters: (a) Neutral lipid fraction: the lipids were converted to their methyl esters by treatment with NaOH/methanol followed by BF_3/methanol (10), (b) Polar lipid fraction: an aliquot of the polar lipid fraction containing ca. 20 mg lipid first was reduced to 5 mL on a rotary evaporator at room temperature. The contents of the flask were quantitatively transferred to a 15 mL centrifuge tube with hexane and the remaining solvent was removed under nitrogen. The residue was dissolved in 1.0 mL of isooctane containing 2 mg of the internal standard methyl henicosanoate. The lipids then were converted to their methyl esters by treatment with KOH/methanol followed by saturated ammonium acetate solution as described by Maxwell and Marmer (11).

Equipment: GC analyses were carried out on a Hewlett Packard 5880A level 4 capillary gas chromatograph (Hewlett-Packard, Palo Alto, CA), equipped with a flame ionization detector, magnetic tape storage capability and a Model 7672A automatic sampler. The column used for all analyses was a 50 m x 0.25 mm I.D. fused silica SP2340 column (Quadrex, New Haven, CT). Carrier gas was helium at a flow of 1 mL/min and make-up gas was nitrogen at a flow of 30 mL/min. The temperature program was: 150°C-170°C at 0.4°C/min, then 1°C/min to 200°C, at which temperature the oven was held for a maximum of 40 min until all FAME's had been eluted.

Determination of FAME's identity and reference standards. Initial identification of FAME's was made by injecting the unknown samples into a Hewlett-Packard 5992B GC-Mass spectrometer to identify the major components in the mixture. Verification of other constituents was made by peak enhancement of unknown components using authentic compounds and by retention time analysis of unsaturated FAME's before and after hydrogenation.

A specially prepared reference standard containing 18 FAME's common to chicken lipids was obtained (Nu Chek Prep, Inc., Elysian, MN). This standard was chromatographed after the automated analysis of each group of 8 samples to ascertain whether changes had occurred in retention times and peak shape due to instrumental variations and to provide data needed to determined individual correction factors (10).

STATISTICAL ANALYSIS

After analysis by capillary gas chromatography (11) of the fatty acid methyl esters, the normalized data (weight percent of total FAME) from the individual gas chromatograms were consolidated (12). The data were subjected to an analysis of variance and Bonferroni mean separation techniques (13), to discern statistically significant differences in profiles as a function of air and vacuum packaging. In addition to normalized reports, use of an internal standard during GC analysis allowed the data to be tabulated and statistically analyzed in gravimetric units that were deemed appropriate by Kinsella *et al.* (14); (mg fatty acid/100 g tissue).

RESULTS AND DISCUSSION

After irradiation of the chicken tissue the lipids were extracted and separated by a technique that allows for the simultaneous isolation and separation of the lipids into their neutral and polar lipid subfractions (9). By the use of this technique, the small but significant polar lipid fraction may be analyzed apart from the more abundant neutral lipids. The utility of isolating separate neutral and polar lipid fractions may be verified by observing the differences between the fatty acid profiles in Tables 1 and 3. Subtle changes in the poly- unsaturated fatty acids as the result of irradiation would be difficult to detect if those fatty acids were analyzed as part of an intact total lipid mixture.

The data for the fatty acid profiles of the neutral lipids of non-irradiated and irradiated chicken muscle are assembled in Tables 1 and 2 and the fatty acid profiles of polar lipids are found in Tables 3 and 4. The data for the neutral and polar lipids are presented in two formats: as normalized reports (% of total fatty acid - Tables 1 and 3) and as gravimetric reports (mg/100 g tissue in Tables 2 and 4). The latter format provides fatty acid data as absolute amounts per tissue portion, which is consistent with most food composition tables. The normalized reports, on the other hand, eliminate the bias in gravimetric reports caused by the fattiness of the tissue.

The individual fatty acids in Tables 1-4 are grouped as saturated, trans- -monoene, cis-monoene, diene, and nondienoic polyene. Those compounds that are not identified are grouped under the appropriate columns as either saturated or unsaturated sums as determined by hydrogenation studies (Materials and Methods). Data that show statistically significant deviations (all $P < 0.05$) from the non-irradiated controls are indicated by superscript^{b} in the tables. Each line in the tables provides comparisons that are independent of the comparisons of other lines.

Saturated fatty acids. About a third of the fatty acids of both the neutral and polar fractions are saturated (Tables 1 and 3). In both cases the major fatty acids are 16:0 and 18:0. Only 0.1% of the saturated fatty acids remained unidentified in either fraction. Comparisons were made between the control samples and samples irradiated at 1, 3, 6 and 10 kGy respectively using both air and vacuum packaging. Significant differences were found only for some of the minor fatty acids such as 17:0 and 19:0 and inconsistently relative to irradiation dosages (Tables 1 and 3). The gravimetric results (Tables 2 and 4) for the same fatty acids show a similar picture, that is there were only a few significant differences in the minor fatty acids regardless of dosage.

Trans-monoenoic fatty acids. The trans-monoenoic fatty acids were detected in higher amounts in the neutral lipid fractions (> 1.1% in the neutral vs ~ 0.7% polar in the normalized reports). The only significant differences between control and irradiated samples occurred for 16:1ω7t in the neutral and polar reports (Tables 1 & 3). No consistant pattern between packaging or dose level could be discerned. The differences among the trans fatty acids in the gravimetric reports were even less pronounced than in the normalized findings (Table 2 and 4).

Monoenoic fatty acids. This is the largest class of acids (> 50%) found in the neutral lipid fraction of chicken muscle tissue and the greatest unsaturated class in the polar fraction. Oleic acid (18:1ω9c) represents the largest portion of the total cis-monoenes and is the fatty acid consumed in the largest amount in edible tissue (Tables 2 and 4). Remarkably, only minor differences were detected among the four cis-monoenes regardless of treatment in both normalized and gravimetric reports.

Dienoic fatty acids. Only two dienoic fatty acids were found in the chicken muscle tissue: the essential fatty acid 18:2ω6c and 20:2ω6c. The total amounts of these acids are similar in both the neutral and polar fractions (18% vs 15%). As may be observed from the Tables, the dienoic acid levels were unaffected by radiation treatment under all experimental conditions.

Nondienoic polyenoic fatty acids. This nutritionally important class of fatty acids is isolated mainly in the polar fractions, whereas only small amounts of these compounds appear in the neutral profiles (Tables 1 and 3). This fatty acid class has received widespread attention because it contains the essential fatty acid arachidonic acid (20:4ω6c) and all of the important ω3 fatty acids. Because of the highly unsaturated nature of the polyenoic fatty acids, they are prone to oxidative instability and may be expected to undergo some changes during radiolytic treatment. Yet, of all treatment levels studied only slight differences were found among the polar nondienoic polyenoic fatty acids at the 10 kGy level in vacuum packaging (Table 3). When these same data were compiled as absolute amounts of fatty acids, the differences were even less apparent (Table 4).

CONCLUSION

This investigation attempted to establish whether irradiation of chicken muscle tissue at -20° resulted in alterations in known fatty acids in muscle or in the formation of

radiolytically induced gas chromatographable fatty acids or other artifacts. Tables of the fatty acid profiles were compiled as normalized reports and as gravimetric reports. The latter were included to gauge the effects of irradiation on the basis of actual changes in mg amounts of fatty acids in edible tissue. In the range of radiation levels studied (0-10 kGy) only minor changes at some doses to the normalized fatty acid profiles were observed while these differences were not apparent when the data were compiled in gravimetric tables. The total unidentified fatty acids (<.5% neutral fractions, and <1.4% polar fractions in normalized reports) showed little change with varying radiation treatments, and these unidentified compounds appeared to be identical in both control and irradiated samples. Packaging, air or vacuum, had little effect on the irradiated samples. Therefore, within the levels of detectability by flame ionization-gas chromatography no radiolytically induced fatty acids or other artifacts could be detected at any dosage level, and radiolytic alteration to the composition of natural fatty acids was virtually undetectable as well.

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Table 1. Fatty Acid Composition[a] of Nonirradiated and Irradiated (-20°C) Neutral Lipid Fractions

(Normalized %)

Fatty Acid	RADIATION DOSE								
	0 kGy	1 kGy		3 kGy		6 kGy		10 kGy	
		Air	Vac	Air	Vac	Air	Vac	Air	Vac
Saturated									
14:0	0.87	0.86	0.86	0.86	0.85	0.86	0.86	0.88	0.86
15:0		0.01	0.02			0.01	0.04[b]	0.01	0.01
16:0	22.94	23.25	23.12	23.31	23.35	23.10	22.79	22.93	23.31
17:0	0.12	0.12	0.11[b]	0.12	0.12	0.12	0.12	0.12	0.12
18:0	5.30	5.32	5.27	5.30	5.40[b]	5.36	5.28	5.27	5.42[b]
ai19:0	0.08	0.08	0.08	0.08	0.06	0.07	0.08	0.08	0.08
19:0		0.01[b]		0.01[b]					
20:0	0.08	0.08	0.08	0.08	0.06	0.08	0.08	0.09	0.09
24:0		0.01	0.01	0.01	0.01		0.01	0.01	0.01
Unidentified Sum	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total Saturated	29.49	29.84	29.65	29.87	29.95	29.70	29.36	29.49	29.88
Unsaturated									
Trans Monoene									
16:1ω7τ	0.53	0.49[b]	0.49[b]	0.49[b]	0.49[b]	0.49[b]	0.50[b]	0.51[b]	0.49[b]
18:1ω9τ	0.55	0.48	0.55	0.57	0.63	0.71[b]	0.65[b]	0.66[b]	0.67[b]
Sum	1.08	0.97	1.04	1.06	1.12	1.20	1.15	1.17	1.16
Cis Monoene									
16:1ω7c	7.86	7.84	8.11	8.04	7.78	7.81	7.89	7.98	7.75
18:1ω9c	40:38	40.38	40.00	40.13	40.52	40.17	40.05	40.04	40.18
18:1ω7c	2.45	2.45	2.43	2.42	2.43	2.39	2.40	2.41	2.42
20:2ω9c	0.32	0.33[b]	0.32	0.32	0.33[b]	0.32	0.32	0.32	0.32
Sum	51.01	51.00	50.86	50.91	51.06	50.69	50.66	50.75	50.67
Diene									
18:2ω6c	15:45	15.21	15.31	15.00	15.04	15.25	15.37	15.26	14.95
20:2ω6c	0.14	0.13	0.14	0.13	0.13	0.13	0.14	0.14	0.13
Sum	15.59	15.34	15.45	15.13	15.17	15.38	15.51	15.40	15.08
Nondieneoic Polyene									
18:3ω3c	0.71	0.69	0.70	0.69	0.67[b]	0.70	0.70	0.71	0.68
20:3ω6c	0.20	0.19	0.20	0.19	0.19	0.19	0.21	0.20	0.19
20:4ω6c	0.35	0.33	0.38	0.32	0.31	0.33	0.41	0.35	0.34
20:5ω3c									
22:4ω6c	0.11	0.11	0.12	0.10	0.10	0.11	0.13	0.11	0.10
22:5ω3c	0.01	0.01	0.05[b]	0.06[b]	0.04[b]	0.04[b]	0.08[b]	0.06[b]	0.04[b]
22:5ω6c									
22:6ω3c									
Unidentified Sum	0.45	0.45	0.45	0.46	0.46	0.44	0.45	0.45	0.43
Total Monoene	52.09	51.97	51.90	51.97	52.18	51.89	51.81	51.92	51.83
Total ω3 Polyene	0.72	0.70	0.75	0.75	0.71	0.74	0.78	0.77	0.72
Total ω6 Polyene	0.66	0.63	0.70	0.61	0.60	0.63	0.75	0.66	0.63
Total Unsaturated	69.51	69.09	69.25	68.92	69.11	69.08	69.30	69.20	68.71

[a]Tabulated values are averaged over 4 samples. [b] Tabulated values were significantly different from 0 kGy dose means by Bonferroni LSD (13). Fatty acid structures are indicated by [chain length: number of methylene-interrupted double bonds]; ω3: double bonds progress toward carboxylate functionality from the third carbon from terminal methyl group (ω3 carbon). ai = anteiso (CH_3 on ω3 carbon).

Table 2. Fatty Acid Composition[a] of Nonirradiated and Irradiated (-20°C) Neutral Liquid Fractions

(mg/100 g tissue)

Fatty Acid	RADIATION DOSE								
	0 kGy	1 kGy		3 kGy		6 kGy		10 kGy	
		Air	Vac	Air	Vac	Air	Vac	Air	Vac
Saturated									
14:0	27.74	27.64	25.17	27.14	26.98	26.61	28.09	27.72	27.83
15:0		0.19	0.59	0.10	0.05	0.31	1.29[b]	0.26	0.65
16:0	732.77	747.17	676.30	732.22	743.96	712.95	740.94	721.72	753.88
17:0	3.80	3.75	3.24	3.66	3.69	3.65	3.89	3.79	3.82
18:0	169.35	170.95	154.12	166.64	171.96	165.36	171.75	165.91	175.09
ai19:0	2.56	2.71	2.29	2.63	1.88	2.13	2.56	2.42	2.62
19:0		0.23[b]		0.24[b]	0.09[b]				
20:0	2.51	2.58	2.34	2.58	1.89	2.61	2.76	2.72	2.90
24:0		0.27	0.19	0.27	0.18	0.08	0.31	0.18	0.34
Unidentified Sum	3.31	3.15	2.87	3.14	3.07	3.09	3.34	3.30	3.26
Total Saturated	942.04	958.64	967.11	938.62	953.75	916.79	954.93	928.02	970.39
Unsaturated									
Trans Monoene									
16:1ω7τ	16.88	15.79	14.30[b]	15.42	15.48	15.23	16.39	16.12	15.86
18:1ω9τ	17.54	15.41	16.12	17.91	20.07	21.93	21.04	20.67	21.68
Sum	34.42	31.20	30.42	33.33	35.55	37.16	37.43	36.79	37.56
Cis Monoene									
16:1ω7c	250.89	252.13	237.16	252.12	247.86	240.78	256.52	251.12	250.65
18:1ω9c	1289.50	1297.70	1169.90	1261.20	1290.00	1238.80	1302.50	1260.30	1299.00
18:1ω7c	78.17	78.56	70.92	76.10	77.29	73.60	78.12	75.99	78.32
20:1ω9c	10.34	10.48	9.38	10.12	10.52	10.01	10.56	10.07	10.48
Sum	1628.90	1638.87	1487.36	1599.54	1625.67	1563.19	1647.60	1597.48	1638.45
Diene									
18:2ω6c	493.51	488.81	447.80	471.23	478.54	470.34	499.94	480.44	483.32
20:2ω6c	4.37	4.29	3.99	4.14	4.12	4.13	4.59	4.34	4.19
Sum	498.24	493.10	451.79	475.37	482.66	474.47	504.53	484.78	487.51
Nondieneoic Polyene									
18:3ω3c	22.58	22.26	20.39	21.82	21.50	21.46	22.69	22.40	22.05
20:3ω6c	6.41	6.24	5.95	6.06	6.03	5.99	6.82	6.41	6.10
20:4ω6c	11.19	10.68	11.03	10.05	9.71	10.26	13.32	11.17	10.84
20:5ω3c									
22:4ω6c	3.55	3.42	3.59	3.18	3.18	3.31	4.28	3.59	3.34
22:5ω3c	0.43	0.39	1.44	1.78	1.32	1.36[b]	2.48[b]	1.95[b]	1.33
22:5ω6c									
22:6ω3c									
Unidentified Sum	14.40	14.35	13.32	14.55	14.13	13.66	14.79	14.04	14.06
Total Monoene	1663.32	1670.07	1517.78	1632.87	1661.22	1600.35	1685.03	1634.27	1676.01
Total ω3 Polyene	23.01	22.65	21.83	23.60	22.82	22.82	25.17	24.35	23.38
Total ω6 Polyene	21.15	20.34	20.57	19.29	18.92	19.56	24.42	21.17	20.28
Total Unsaturated	2220.12	2220.51	2025.29	2165.68	2199.75	2130.86	2253.94	2178.61	2221.24

[a] See footnote a, Table 1, [b] See footnote b, Table 1

Table 3. Fatty Acid Composition[a] of Nonirradiated and Irradiated (-20°) Polar Lipid Fractions (Normalized %)

Fatty Acid	RADIATION DOSE								
	0 kGy	1 kGy		3 kGy		6 kGy		10 kGy	
		Air	Vac	Air	Vac	Air	Vac	Air	Vac
Saturated									
14:0	0.28	0.28	0.27	0.30	0.33	0.30	0.27	0.32	0.30
15:0									
16:0	19.85	19.98	20.26	20.05	20.47[b]	20.20	19.85	19.77	20.17
17:0	0.13	0.13	0.13	0.13	0.12[b]	0.13	0.13	0.13	0.13
18:0	13.62	13.48	13.26	13.43	13.13	13.67	14.12	14.08	13.54
ai19:0	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.12	0.12
19:0		0.04							0.30
20:0		0.06[b]			0.02			0.01	0.02
24:0	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.03
Unidentified Sum[c]									
Total Saturated	34.03	34.12	34.07	34.07	34.21	34.45	34.51	34.47	34.61
Unsaturated									
Trans Monoene									
16:1ω7τ	0.27	0.27	0.25[b]	0.28[b]	0.27	0.25[b]	0.26[b]	0.26[b]	0.28[b]
18:1ω9τ	0.39	0.33	0.43	0.44	0.42	0.41	0.44	0.45	0.42
Sum	0.66	0.60	0.68	0.72	0.69	0.66	0.70	0.71	0.70
Cis monoene									
16:1ω7c	1.66	1.69	1.76	1.89	2.10[b]	1.67	1.69	1.64	1.94[b]
18:1ω9c	18.98	19.09	19.47	19.81	20.65[b]	19.12	19.26	18.80	20.06
18:1ω7c	3.55	3.44	3.56	3.51	3.41	3.36	3.50	3.54	3.41
20:1ω9c	0.27	0.26	0.27	0.28	0.28	0.27	0.28	0.26	0.27
Sum	24.46	24.48	25.06	25.49	26.44	24.42	24.73	24.24	25.68
Diene									
18:2ω6c	17.90	17.61	17.92	17.66	17.18[b]	17.75	17.63	17.78	17.63
20:2ω6c	0.50	0.48	0.51	0.51	0.49	0.52	0.47	0.49	0.49
Sum	18.40	18.09	18.43	18.17	17.67	18.27	18.10	18.27	18.12
Nondieneoic Polyene									
18:3ω3c	0.13	0.10	0.13	0.14	0.16	0.13	0.12	0.13	0.15
20:3ω6c	1.52	1.56	1.57	1.58	1.49	1.56	1.51	1.54	1.51
20:4ω6c	11.43	11.48	11.09	10.96	10.62[b]	11.43	11.34	11.46	10.46[b]
20:5ω3c	0.71	0.71	0.63	0.67	0.67	0.67	0.60	0.64	0.70
22:4ω6c	2.71	2.65	2.66	2.58	2.45[b]	2.63	2.69	2.74	2.42[b]
22:5ω3c	1.75	1.73	1.70	1.67	1.65[b]	1.71	1.68	1.72	1.58[b]
22:5ω6c	0.72	0.72	0.69	0.68	0.65	0.70	0.70	0.73	0.62[b]
22:6ω3c	2.06	2.09	2.00	1.98	2.01	2.07	1.95	2.02	1.88[b]
Unidentified Sum	1.20	1.35	1.37	1.21	1.20	1.20	1.20	1.25	1.18
Total Monoene	25.12	25.08	25.74	26.21	27.13	25.08	25.45	24.95	26.38
Total ω3 Polyene	4.65	4.63	4.46	4.46	4.49	4.58	4.35	4.51	4.31
Total ω6 Polyene	16.38	16.41	16.00	15.80	15.21	16.32	16.24	16.47	15.01
Total Unsaturated	65.75	65.56	66.00	65.85	65.70	65.45	65.39	65.45	65.00

[a]See footnote a, Table 1, [b]see footnote b, Table 1, [c] no unidentified saturated fatty acids were found in the polar lipid fractions.

Table 4. Fatty Acid Composition[a] of Nonirradiated and Irradiated (-20°) Polar Lipid Fractions (mg/100 g tissue)

Fatty Acid	RADIATION DOSE								
	0 kGy	1 kGy		3 kGy		6 kGy		10 kGy	
		Air	Vac	Air	Vac	Air	Vac	Air	Vac
Saturated									
14:0	1.03	1.08	1.01	1.13	1.19	1.07	0.99	1.20	1.12
15:0									
16:0	74.48	77.74	75.51	76.15	74.76	72.88	72.21	73.77	74.31
17:0	0.50	0.50	0.47	0.49	0.45	0.46	0.48	0.50	0.48
18:0	51.10	52.45	49.45	51.01	47.89	49.33	51.39	52.51	49.87
ai19:0	0.41	0.43	0.39	0.40	0.36	0.36	0.37	0.44	0.43
19:0		0.16[b]							0.11[b]
20:0		0.22[b]			0.08			0.05	0.08
24:0	0.15	0.14	0.15	0.12	0.13	0.15	0.15	0.15	0.13
Unidentified sum[c]									
Total Saturated	127.67	132.72	126.98	129.30	124.86	124.23	125.59	128.62	126.61
Unsaturated									
Trans Monoene									
16:1ω7	1.02	1.04	0.92	1.07	0.99	0.91	0.95	0.98	1.03
18:1ω9	1.48	1.28	1.62	1.67	1.54	1.48	1.60	1.66	1.54
Sum	2.50	2.32	2.54	2.74	2.53	2.39	2.55	2.64	2.57
Cis Monoene									
16:1ω7c	6.23	6.57	6.56	7.17	7.72	6.03	6.15	6.12	7.16
18:1ω9c	71.21	74.27	72.58	75.27	75.68	68.92	70.00	70.15	73.93
18:1ω7c	13.30	13.38	13.27	13.34	12.47	12.13[b]	12.73	13.21	12.55
20:1ω9c	1.00	1.03	1.01	1.07	1.02	0.98	1.00	0.96	0.99
Sum	91.74	95.25	93.42	96.85	96.89	88.06	89.88	90.44	94.63
Diene									
18:2ω6c	67.16	68.53	66.81	67.09	62.79	64.05	64.13	66.30	64.93
20:2ω6c	1.86	1.85	1.90	1.95	1.78	1.89	1.72	1.81	1.80
Sum	69.02	70.38	68.71	69.04	64.57	65.94	65.85	68.10	66.73
Nondieneoic Polyene									
18:3ω3c	0.48	0.40	0.49	0.55	0.58	0.45	0.45	0.47	0.57
20:3ω6c	5.71	6.06	5.84	5.99	5.42	5.63	5.51	5.74	5.56
20:4ω6c	42.89	44.70	41.35	41.63	38.72	41.28	41.25	42.76	38.50
20:5ω3c	2.68	2.76	2.33	2.56	2.45	2.41	2.18	2.38	2.59
22:4ω6c	10.17	10.32	9.90	9.80	8.92	9.51	9.79	10.23	8.91[b]
22:5ω3c	6.57	6.73	6.32	6.35	6.03	6.16	6.10	6.41	5.83
22:5ω6c	2.72	2.80	2.58	2.60	2.37	2.53	2.56	2.73	2.29[b]
22:6ω3c	7.73	8.15	7.44	7.50	7.32	7.47	7.09	7.54	6.92
Unidentified Sum	5.12	4.73	4.45	4.07	4.36	4.32	4.45	4.71	4.36
Total Monoene	94.24	97.57	95.96	99.59	99.42	90.45	92.43	93.08	97.20
Total ω3 Polyene	17.46	18.04	16.58	16.96	16.38	16.49	15.82	16.80	15.91
Total ω6 Polyene	61.49	63.88	59.67	60.02	55.43	58.95	59.11	61.46	55.26
Total Unsaturated	247.33	254.60	245.37	249.68	240.16	236.15	237.66	244.15	239.46

[a] see footnote a, Table 1, [b] see footnote b, Table 1, [c] see footnote c, Table 3.